The Climatological and Geological Evidence in Support of a Warmer and Wetter Early Mars

*Ramses M Ramirez[1], Robert Craddock[2]

1. Earth-life Science Institute, 2. The Smithsonian Institution

The climate of early Mars has been a topic of intense debate for decades. Although most investigators believe that the geology, including the valley networks (Figure 1), indicates the presence of surface water, disagreement has persisted regarding how warm the surface must have been and how long such conditions may have existed. Climate models that only include CO_2 and H_2O as greenhouse gases have been unable to generate warm surface conditions given the faint young Sun. Some models suggest that a continuously warm climate could have been possible by supplementing this CO_2-H_2O warming with either secondary greenhouse gases or CO_2 clouds. Others posit that Mars' climate was cold most of the time, but underwent periodic episodes of transient warming caused by external events, including methane bursts, limit cycles, impacts, or sporadic volcanic events. Here, we argue that a predominantly icy early Mars cannot be reconciled with either the geologic record or climate modeling simulations. Mars may have had a warm and semi-arid climate instead.

Using a single-column climate model, we show that warm and relatively non-glaciated early Mars require only ~1% H_2 and 3 bar CO_2 or ~20% H_2 and 0.55 bar CO_2. In contrast, the reflectivity of surface ice greatly increases the difficulty to transiently warm an initially frozen surface. Surface pressure thresholds required for warm conditions increase ~10 –60% for transient warming models, depending on ice cover fraction. No warm solution is possible for ice cover fractions exceeding 40%, 70%, and 85% for mixed snow/ice and 25%, 35%, and 49% for fresher snow/ice at H_2 concentrations of 3%, 10%, and 20%, respectively. If high temperatures (298 –323 K) were required to produce the observed surface clay amounts on a transiently warm early Mars, we show that such temperatures would have required unrealistically high surface pressures (> 5 –10 bar) for nearly all H_2 concentrations considered (1 –20%).

The geologic evidence does not support a heavily glaciated early Mars. Glacial features, such as cirques, kames, and eskers, are noticeably absent in ancient terrains. Furthermore, the geomorphology strongly suggests that a widespread process, most likely precipitation, was the major erosive agent on early Mars, countering the notion that localized sources of glacial melt from icy highland sheets could have formed these fluvial features, including those in Arabia Terra. Indeed, a recent analysis finds that a global water volume exceeding 5 km was necessary to carve the valley networks, suggesting a paleo-ocean and active hydrologic cycle did exist. Other icy explanations, including limit cycles or impact hypotheses cannot explain the evidence either.

It is possible that early Mars was characterized by a warm and semi-arid climate that produced enough precipitation (e.g. rainfall) to form the ancient valleys. Such an interpretation is consistent with the observed lack of glaciation in ancient terrains, the water amounts necessary to form the older valleys, and the recent estimates for a smaller initial water inventory (< 200 m global equivalent).

Keywords: early Mars, astrobiology, climate, geology

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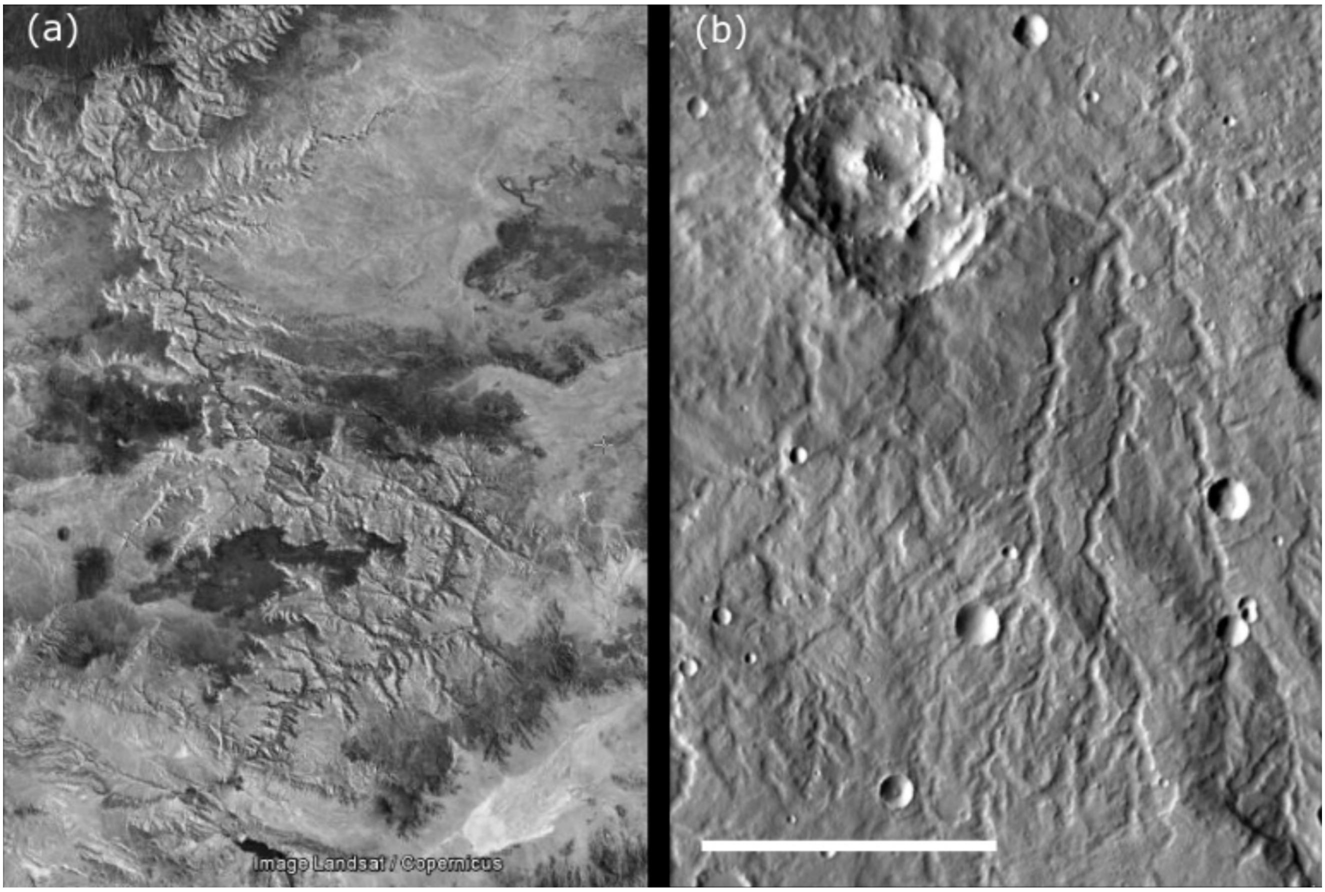

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